Description

METHOD AND APPARATUS FOR PERIODIC SIGNAL DETECTION IN OFDM/DMT SYSTEMS

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to periodic signal detection in a system, and more particularly, to periodic signal detection in an OFDM/DMT system.

[0003] 2. Description of the Prior Art

[0004] Signal detection and receiver training are essential tasks for a digital communication system. Without accurate receiver training algorithms, it is not possible to reliably receive the transmitted data. In orthogonal frequency division multiplexing (OFDM) and discrete multi-tone (DMT) communication systems, data is modulated on tones used by the system.Inverse FFT (IFFT) is performed on the modulated tones to obtain a set of time domain samples called

OFDM symbol for transmission. DMT is mainly used in continuous transmission systems, such as ADSL and VDSL; while OFDM is used in both continuous and burst transmission systems, such as European digital video broadcast (DVB), 802.11 wireless LANs, and 802.16 fixed wireless systems. OFDM/DMT communication systems use a periodic signal to facilitate signal detection, timing/frequency recovery, and channel estimation at the receiver. A periodic signal contains repeated training symbols, which are designed to possess good time domain and/or frequency domain auto-correlation property. The task of periodic signal detection is to detect arrival of data packets or the beginning of a periodic training signal with high probability of detection and low probability of false alarms under severe frequency selective channel fading and strong interferences.

[0005] Most of the existing periodic signal detection methods exploit repeated structures and auto-correlation property of periodic signalin time domain. These methods suffer significant performance degradation when strong narrowband interference (NBI) or Gaussian noise is present. In one approach known in the art, the time domain correlator computes auto-correlation values using current re-

ceived temporal symbol and previous received temporal symbol until the correlation value exceeds a pre-defined threshold.This method, however, requires a large number of multiplication and addition operations. Time domain correlation is also difficult to establish if the received signal is corrupted by narrowband interference.

[0006] Frequency domain methods that correlate tone phases or other information of two consecutive received OFDM symbols achieve excellent periodic signal detectioneven in the presence of strong narrowband interference.For example, in another approach known in the art, two consecutive received temporal symbols are transformed into frequency domain by FFT operation. Two sets of tone phases are computed for the two frequency domain symbols. Correlation of the two sets of tone phases are computed as a metric for periodic signal detection. The computation requires heavy CPU cycles or complex ASIC implementation that amounts to higher system cost.Also, computation of tone phases adds overhead for communication systems that do not use phase information explicitly.

SUMMARY OF INVENTION

[0007] It is therefore a primary objective of the claimed invention to provide a method of periodic signal detection in fre-

quency domain for OFDM/DMT communication systems.

[0008] Briefly described, the claimed invention disclosesa low complexity and high performance method for periodic signal detection in an orthogonal frequency division multiplexing (OFDM) or a discrete multi-tone (DMT) communication system infrequency domain. The method comprises converting received time domain digitized signals to corresponding frequency domain digitized signals, quantizing at least two symbols in frequency domain to obtain quantization information, and utilizing the quantization information to compute a detection metric for periodic signal detection. A double-detection method based on the detection metric is also described.

[0009] These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0010] Fig.1 is a block diagram ofan OFDM/DMT receiver according to the present invention.

[0011] Fig.2 is a block diagram of the periodic signal detector in Fig.1.

[0012] Fig.3 is a diagram of the preamble format of IEEE 802.11a standard.

[0013] Fig.4 is a flow chart of double periodic signaldetection and receiver training according to the present invention.

[0014] Fig.5 is a diagram of the preamble format of ADSL REVERB standard.

DETAILED DESCRIPTION

[0015] Please refer to Fig.1. Fig.1 is a block diagram ofan OFDM/ DMT receiver R1 according to the present invention. The serial-to-parallel converter10 is capable of performing serial-to-parallel conversion on input time domain digi- tized signals. The fast Fourier transform(FFT)module20 is electrically connected to the serial-to-parallel converter10 and transforms the time domain digitized signals to ob- tain frequency spectrum. The demodulator 30 is electri- cally connected to the FFT module20 to perform the de- modulation and comprises a demodulation module 40 for demodulating the frequency domain digital signal and a periodic signal detector 50 electrically connected to the FFT module20. Complex output of the FFT module 20 is denoted as $R_{i,k}$ for the kth tone of the ith received OFDM/ DMT symbol. $R_{i,k}$ can be modeled as a weighted version of the transmitted constellation point corrupted by additive

noise.

$$R_{i,k} = a_{i,k} + b_{i,k} \cdot j = X_{i,k} \cdot H_{i,k} + N_{i,k}, \quad k = 1, \ldots, N.$$

[0016] k: Tone index.

[0017] i: Received OFDM symbol index.

[0018] $R_{i,k}$: Received constellation point for tone k.

[0019] $a_{i,k}$: the real part of $R_{i,k}$.

[0020] $b_{i,k}$: the imaginary part of $R_{i,k}$.

[0021] $X_{i,k}$: Transmitted constellation point for tone k.

[0022] $H_{i,k}$: Channel attenuation for tone k.

[0023] $N_{i,k}$: Noise for tone k.

[0024] $R_{i,k}$ represents a constellation point on the complex plane for tone k of the ith received OFDM symbol. In this invention, constellation points $\{R_{i,1}, R_{i,2}, \ldots, R_{i,N}\}$ and $\{R_{i+1,1}, R_{i+1,2} \ldots, R_{i+1,N}\}$ of two consecutive received OFDM/DMT symbols are used to compute a detection metric

$$D_{i,i+1}$$

as follows:

$$D_{i,i+1} = \sum_{k=1}^{N} \left[w(a_{i,k}) \cdot sign(a_{i,k}) \right] \cdot \left[w(a_{i+1,k}) \cdot sign(a_{i+1,k}) \right] + \sum_{k=1}^{N} \left[w(b_{i,k}) \cdot sign(b_{i,k}) \right] \cdot \left[w(b_{i+1,k}) \cdot sign(b_{i+1,k}) \right]$$

$$= \sum_{k=1}^{N} Q(a_{i,k}) \cdot Q(a_{i+1,k}) + \sum_{k=1}^{N} Q(b_{i,k}) \cdot Q(b_{i+1,k})$$

[0025] Where

$$sign(x)$$

is a sign extraction function:

$$sign(x) = \begin{cases} -1, & if\ x < 0. \\ 0, & if\ x = 0. \\ 1, & if\ x > 0. \end{cases}$$

[0026]

$$W(x)$$

is a measure of reliability of

$$sign(x)$$

:

$$w(x) = \begin{cases} 0, & \text{if } |x| < \text{Threshold}. \\ 1, & \text{otherwise}. \end{cases}$$

[0027]

$$Q(x)$$

is a quantizer that combines

$$w(x)$$

and

$$sign(x)$$

:

$$Q(x) = \begin{cases} -1, & \text{if } x < -\text{Threshold}. \\ 1, & \text{if } x > \text{Threshold}. \\ 0, & \text{otherwise}. \end{cases}$$

[0028] In words this detection metric is the sum of the weighted sign correlations of the real part and the imaginary part of the constellation points $\{R_{i,1}, R_{i,2}, \ldots, R_{i,N}\}$ and $\{R_{i+1,1}, R_{i+1,2} \ldots, R_{i+1,N}\}$.

[0029] The periodic signaldetection criterion is that a periodic signalis detected if $D_{i,i+1}$ is greater than a positive threshold.

[0030] In some burst OFDM systems, the last periodic signal is sign-inverted to signal end of periodic signal (EOP). The same detection metric can be used for theEOP detection. Here the EOP detection criterion is that EOP is detected if $D_{i,i+1}$ is smaller than a negative threshold.

[0031]   Please refer to Fig.2. Fig.2 is a block diagram of the peri-
odic signal detector 50 in Fig.1. The periodic signal detec-
tor50 comprises a quantizer 60 for quantizing input sig-
nals. A sign correlator 70 is electrically connected to the
quantizer 60 for performing a predetermined correlation
to generate a detection metric for periodic signal detec-
tion. And a sign memory 80 is electrically connected to
the quantizer 60 and the sign correlator 70 for providing
to the sign correlator 70 the stored sign information of
the previous symbol obtained from the quantizer 60.

$$S_{i+1}$$

is the collection of the real part and imaginary part signs
of the $(i+1)$th received OFDM/DMT symbol. The quantizer
output

$$Q(S_{i+1})$$

is the set of weighted signs. This implementation realizes
the method of periodic signal detection of this invention
described in the paragraph above. In this manner, the
memory required is minimal since only signs of FFT out-
put are stored.

[0032] Please refer to Fig. 3. Fig.3 is a diagram of the preamble format of IEEE 802.11a standard. S1 to S10 are identical short periodic symbols each having 16 samples. CP is a 32-sample cyclic prefix that protects the long periodic symbols L1 and L2 from inter-symbol interference (ISI) caused by the short periodic symbols S1 to S10. L1 and L2 are identical OFDM symbols each having 64 samples. The method and the system of periodic signal detection in the present invention can be applied to both the short and the long periodic symbols in IEEE 802.11a standard to implement preamble detection.

[0033] HomePlug is a network system utilizing the medium of existing power line wiring in homes and offices for the infrastructure of computer network The HomePlug power line communications system is based on a burst-OFDM scheme for exchanging packetized information, and utilizes preambles for receiver training. The preambles of HomePlug system are very similar to that of IEEE 802.11a. The identity of the repeated symbols guarantees the applicability of the method of periodical symbol detection in this present invention.

[0034] For a periodic signal that containsat least three periodic symbols, like the preamble in IEEE 802.11a standard and

many other systems, two consecutive detections and two thresholds are used for detecting the periodic signal. The periodic signal is detected if $D_{i,i+1}$ is greater than a threshold T1 and $D_{i+1,i+2}$ is greater than another threshold T2,where threshold T1 is smaller than or equal to threshold T2.The first periodic signal detection D1, uses a lower threshold T1 to determine whether the periodic signal is possibly detected. The second periodic signal detection D2, uses a higher threshold T2 to determine whether the periodic signal is really detectedand to reject false alarms.

[0035] Please refer to Fig.4. Fig.4 is a flow chart of double periodic signaldetection and receiver training according to the present invention.

[0036] Step 100: Start double periodic signal detection;

[0037] Step 110: Perform periodic signal detection D1 on first two of three consecutive symbols;

[0038] Step 120: Check if the periodic signal detection D1 succeeds; if so, go to step 130; if not, go to step 110;

[0039] Step 130: Start receiver training;

[0040] Step 140: Perform periodic signal detection D2 on last two of the three consecutive symbols;

[0041] Step 150: Check if the periodic signal detection D2 suc-

ceeds; if so, go to step 170; if not, go to step 160;

[0042] Step 160: Stop the receiver training and go to step 110;

[0043] Step 170: Determine the periodic signal being detected, and continue the receiver training.

[0044] A typical receiver training includes timing/frequency recovery, channel estimation, and/or other functions. In Fig.5, the receiver training is started when periodic signal detection D1 is successful. However, the receiver training can bestarted even before periodic signal detection D1 is successful. That is, the receiver training can be performed concurrently with the periodic signal detection D1.

[0045] There are three possible operating scenarios asdescribed below. For the first scenario, the first periodic signal detection D1 keeps failing so the first periodic signal detection D1 is performed repeatedly as each FFT output is available. In the second scenario,the first periodic signal detection D1 succeeds, but the secondperiodic signal detection D2 fails. The preamble processing is started after the first periodic signal detection D1 and stopped after the secondperiodic signal detection D2. The first periodic signal detection D1 is performed after the secondperiodic signal detection D2. The last possible scenario is both the first periodic signal detection D1 and the secondperiodic

signal detection D2 succeed. The receiver training is started after the first periodic signal detection D1 and continued beyond the secondperiodic signal detection D2.

[0046] Please refer to Fig.5. Fig.5 is a diagram of the preamble format of REVERB in asymmetric digital subscriber line (ADSL) standard.The REVERB signal is adapted to allow the ADSL receiver to adjust its automatic gain control, to perform synchronization and to train the receiver equalizer. The REVERB signal is denoted as C_REVERB in Fig.5 and is used for three times in the ATU–C training sequence. The three REVERB signals contain 512, 1536, and 1024 repeated training symbols respectively. Since there are more than three symbols in each REVERB signal, the claimed double periodic signaldetection can be used to detect arrival of the REVERB signal for ADSL system.

[0047] The present invention disclosesa low complexity and high performance method for periodic signal detection in both continuous and burst transmission OFDM or DMT communication systems in frequency domain. In this invention, the memory required is minimal since only signs of FFT output are stored. It is also provided in the present invention a double detecting method for periodic signal that contains at least three periodic symbols.In this dou-

ble detecting method, two consecutive detections and two thresholds are used for detecting periodic signals. In this manner the false alarm of periodic signal detection is avoided and the receiver training can be started before the periodic signal detection is confirmed. The embodiments of the basic detection metric and the double detecting method are also provided.

[0048] Those skilled in the art will readily observe that numerous modifications and alterations of the device may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.